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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

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☐ *Additional inventors are being named on the _______ separately numbered sheets attached hereto*

TITLE OF THE INVENTION (500 characters max)

Compound Phase Encoding for Absolute Position of Printed Servo Patterns

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ENCLOSED APPLICATION PARTS ***(check all that apply)***

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METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT

☑ Applicant claims small entity status. See 37 CFR 1.27.

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Respectfully submitted,

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Date 02/14/2003

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REGISTRATION NO. *(if appropriate)*

Docket Number:

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USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

Provisional Patent Application of

Bill R. Baker

For

TITLE: COMPOUND PHASE ENCODING FOR ABSOLUTE POSITION OF PRINTED SERVO PATTERNS

CROSS-REFERENCE TO RELATED APPLICATIONS Not Applicable

FEDERALLY SPONSORED RESEARCH Not Applicable

SEQUENCE LISTING OR PROGRAM Not Applicable

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to printing or rapidly transferring fixed servo reference data to surfaces such as those of magnetic storage media and, more particularly, to printing servo data with compound phase patterns that provide absolute position information, that are well suited to commercial data channel chips, and that require relatively little space on the recording surface.

2. Description of the prior art

Modern magnetic recording systems have servo information or position markers written in an interleaved fashion on the same surface on which data are recorded. To simplify the system the same head is used to read the user data and the servo information. Various special formats are used for the servo information to enable using measurements and subsequent signal processing to determine the position of the read head relative to the center of the desired data track. A head movement mechanism and servo control system keep the read head close enough to the data track center to assure reliable read back of the previously written user data.

Early hard disk systems used a special machine, a servo track writer (STW), see U. S. Patent 5333140 to Moraru, et al., to record the servo information on the disk surface. The STW includes a clamping system to hold the hard disk drive (HDD) in a fixed reference position and an external motor with a laser or optical encoder to accurately move a reference pin that extended into the HDD. The actuator or head positioning mechanism of the HDD is biased against the pin so the write head of the HDD can be placed at any desired radius by moving the external motor according to its encoder system. The STW also includes a clock head that is temporarily placed on a surface of the disk by means of a special aperture in the HDD case. Circuitry of the STW writes a clock signal or timing reference by applying a pattern of write current to the clock head. The clock head reads the timing reference signal as the HDD write head is moved to any desired radius. Since the timing reference is fixed relative to the disk it is possible to write servo patterns of a desired form as function of radius and angle on

the disk. Related STW are used for removable media such as the ZIP floppy diskette system manufactured by Iomega Corporation.

The STW must turn the disk through at least one revolution to write the servo information, and another fraction of a revolution is required to move the head to the next radius. Many servo patterns use the edges of special bursts or sub elements in the determination of the position from the read back signal, so it is necessary to write the servo bursts at radial displacements of a fraction of the data track width. Therefore it is usually required to write two or more servo tracks for each data track. Since HDDs now have about one hundred thousand or more data tracks, it may require tens of minutes to write the servo pattern.

Because the enclosure of the HDD is required to have openings for the clock head and for the reference pin it is necessary to use the STW in a special clean room to avoid contamination of the head-media interface. It is expensive and difficult to maintain the complex STW in such a clean environment.

A new approach was offered by a "printing" method (Ishida, T., et al., "Printed Media Technology for an Effective and Inexpensive Servo Track Writing of HDDs", IEEE Trans. Magn., p1875, 2001 and Sugita, R., et al., "A Novel Magnetic Contact Duplication Technique for Servo-Writing on Magnetic Disks", IEEE Trans. Magn. p2285, 2001). In that method the desired servo pattern is replicated in a "master disk" consisting of a silicon substrate about one millimeter thick with strips of highly permeable cobalt about one half micron thick embedded in the silicon. The face of the master containing the cobalt elements is placed in contact with a D.C. erased slave disk. Then a permanent magnet producing an oppositely directed field is brought close to the back surface of the master and is rotated one revolution relative to the master-slave pair. The cobalt elements shield portions of the slave disk leaving them in the original D.C. state, but gaps in the cobalt pattern allow the field to penetrate. The field is concentrated at the gaps and the increased fringing components reverse the magnetization of the adjacent portions of the slave disk. This rapid transfer of the pattern to the entire surface of the slave disk, or "printing", is done as the last step at the end of a conventional disk manufacturing line.

Important feature sizes, typically line widths and the thickness of cobalt elements, have been steadily decreasing, but the transition density of printing currently lags that of conventional write heads. Direct printing of a conventional edge of burst servo pattern resulted in poor performance at contemporary data densities, (Ishida, et al., "Demodulation of servo tracking signals printed with a lithographically patterned master disk", *IEEE Trans. Magn.*, Vol. 37, No. 4, Jul., 2001, pp1412-1415).

The conventional Gray codes would provide the absolute radial position, but they are not well suited to the printing process and result in fuzzy transitions at track edges. Unfortunately those codes occupy a large part of the surface, they are not well adapted to the architecture of commercial channel chips, and they require larger variations of widths of lines and spaces. The large variations of feature sizes exacerbate noise sources of the printing process. Proper choice of geometry including width and thickness of the cobalt elements and width of the gaps is necessary to assure magnetic switching of the slave medium next to the gaps of the master without saturating the cobalt film to produce "secondary gaps" and consequent writing of spurious pulses or noise (Saito, A., et al., " Magnetic printing technique for longitudinal thin film media with high coercivity of 6000 Oe", J. Appl. Phys., V 91, p 8688, 2002 and Baker, "Tradeoffs for magnetic printing of servo patterns", J. Appl. Phys., p8691, 2002).

Therefore it was proposed in US Patent 6304407 to Baker, et al., to use the printed pattern as a reference system for self-servowriting (SSW). Because the printing method involves several processes such as optical diffraction, diffusion in the photo resist, and shadowing during sputtering of the cobalt, it is difficult to produce square corners or small radii of curvature at the ends of the cobalt lines. Therefore phase methods are used as in U.S. Pat. 3686649 to Behr, for the position information, and the phase is measured by discrete Fourier transforms (DFT) in the manner of U.S. Patent 5784296 to Baker, et al. In this method the ends of the bars in the inclined phase elements are excluded from the sample window, and pulses are measured at the long, clean edges of magnetic transitions.

After assembly of the HDD it is removed from the clean room and placed on a self-test rack where it begins its self-servowriting directed by the embedded firmware. Well known self-test methods measure possible pattern eccentricity and any minor errors of the position information for each servo block printed on the disk. Then corrections are applied for subsequent writing of a final servo pattern. The relatively low additional cost of printing one surface of a disk has eliminated the need for an expensive STW and the clean room in which to operate it.

Mitsubishi Corporation using well-known magneto-optic (MO) techniques subsequently developed an alternate printing method. The same pattern described above is first replicated as a chromium on glass reticle or mask. Such masks are commonly created by photolithography. Opaque features are left as a thin chromium film on a transparent glass substrate. In this case too the slave disk is initially D. C. erased, and the printing magnet applies a field in the opposite direction. The applied field is a bit lower than the coercivity of the slave so its magnetization is preserved until a laser is flashed through the mask. The brief laser pulse heats areas under gaps of the pattern. The surface temperature of the recording film rises quickly decreasing the local coercivity and allowing the selected regions to switch magnetization directions.

This contact magneto-optic method also has limitations due to diffraction and to the difficulty of maintaining the small space between reticle and slave disk and due to reflections between the two. Using an antireflective coating on the reticle is difficult because the energy density of the laser irradiation damages the coating. Some of these problems are ameliorated by a projection printing demonstration (Wang, L., et al., "Photo thermal patterning on magnetic media", J. Appl. Phys., V 91, p8685, 2002).

As is well known in the disk drive industry the number of servo wedges or position bearing segments of the disk must increase as the track density increase. Drives now have a few hundred wedges and the trend is toward higher densities. The patterns are made by various processes such as fine scale lithography, which is also used in the manufacture of semiconductors and read-write heads for disk drives.

The SSW process described above utilized early printed disks when the critical feature sizes or printable line and space widths were greater than one micron. There was no absolute position information, but it was adequate to move the head in small steps relative to a local coordinate. That was sufficient to write each of the final servo tracks as the head was inched along the radial extent of the HDD. The relatively large printed reference patterns are simply overwritten after the final pattern has been completed.

It is also well known that fields at the edges of conventional write heads are poorly controlled, (Van Herk, "Analytical expressions for side fringing response and crosstalk with finite head and track widths", *IEEE Trans. Magn.*, Vol. 13, No. 6, Nov., 1977, pp1764-1766 and Tsang, et al., "Disk-noise induced peak jitters in high density recording", *IEEE Trans. Magn.*, Vol. 29, No. 6, Nov., 1993, pp3975-3977.) Therefore the phase encoding methods of the present invention offers a bettersolution for the final servo pattern at extremely high track densities.

BRIEF SUMMARY OF THE INVENTION

One object of the present invention is to provide convenient absolute position information from a printed pattern so that large displacements of a read sensor of a magnetic recording system or other track oriented machine in the cross track direction can be verified from only the local data.

Another object of this invention is to improve the magnetic printing by reducing variations in feature size and to better match the pattern to the channel chip capabilities.

Another objective is to reduce the area required for the printed pattern so that it might be used directly as the final servo pattern without rewriting in a SSW mode.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagram of a printed pattern of the prior art.

FIG. 2 is an attempt to print Gray codes according to prior art.

FIG. 3A is a diagram in logical coordinates that defines phase encoded position elements of the present invention.

FIG. 3B is an example diagram in logical coordinates of fine position and absolute position phase elements.

FIG. 4A is a diagram of the phase differences of **A** and **B** fine elements of Fig. 3B.

FIG. 4B is a diagram of phase variations of the absolute **C** burst of Fig. 3B.

FIG. 4C is a diagram of phase variations of the absolute **D** burst of Fig. 3B.

FIG. 5 shows phase variations of the **C** and **D** bursts vs the cross track position **y**.

FIG. 6 shows phase variations in an example positional value phase system.

FIG. 7 shows a system with reduced features to improve surface utilization efficiency.

DETAILED DESCRIPTION

The invention comprises two or more phase-encoded subsystems combined in a novel manner that provides an absolute position coordinate. The resulting pattern is well suited to available methods for printing servo patterns on magnetic recording media such as disks or linear tapes. The servo pattern can be easily read and decoded using commercial R/W (Read Write) or channels chips. This method can be used as reference for SSW (Self Servo Writing), and it requires much less surface area, so it can also be used as a final servo pattern.

A schematic diagram in logical coordinates of Fig. 1 shows the magnetization distribution of printed patterns of the prior art. The abscissa or horizontal coordinate **x** is a down-track coordinate proportional to the time at which the read head encounters an element of the pattern. The ordinate, **y**, is a cross-track coordinate which changes as the head moves to a new track. The white background of the diagram corresponds to a "background" state of magnetization directed generally in the longitudinal direction of the tracks, either toward the

right or toward the left (positive or negative **x** direction). The crosshatched pattern elements are regions where the magnetization has been reversed by the printing process.

The head and read channel produce a pulse as the head crosses a transition between the two states of magnetization. The sign of the pulse when the head leaves the background state is opposite that created at the return to the background. The absolute sign of the pulse at exit from the background is not critical to this invention, and most modern read channels can be configured to work with any consistent background state.

For a linear tape system with a linear actuator that moves the read head straight across the tracks, Fig. 1 resembles the magnetization distribution in physical coordinates on the tape.

For a disk drive with a linear actuator the servo pattern of Fig. 1 would map onto a wedge shaped region in physical coordinates so that vertical lines of Fig. 1 would diverge for increasing radius. For a disk with rotary actuator the constant time lines of the servo wedge would also be arcuate as well as diverging for larger radius.

The servo block of the schematic diagram of Fig. 1 comprises elements **10** that are centered relative to the data tracks. Those track centered data include elements for clock synchronizing, certain special flags such as a SAM (Servo Address Mark), an Index and other markers and Gray code bits, **18**, for coarse position information. Conventional edge of burst fine position elements **14** are offset from the track centerlines. The dashed lines suggest boundaries of the user data tracks. Generally the number of lines and spaces in the timing segment **10** would be greater, but this diagram shows the concepts in a greatly simplified form.

Demonstrations of demodulation using this prior art, (ibid. Ishida), were made at relatively low track density. The magnetic printing from a permeable film pattern does not work well for Gray codes, **18**, where some small regions should be reversed in the middle of the surrounding region of the background magnetization state. During printing an external field is applied in order to switch the regions under the openings of the pattern. However, the

magnetic flux tends to stay in the film in large areas such as **18**. Flux flows around smaller openings in the film leaving those portions of the slave surface unaffected.

Another problem is that large film areas, required in the usual Gray codes, may become saturated and lose their shielding characteristic. That allows flux to penetrate the film and create unwanted pulses or noise. At large gaps in the film, **16**, the fringing field is smaller, and the magnetization may not be completely reversed.

In the prior art special Gray code structures such as Fig. 2 have been studied. In that format every Gray code cell, of length **L** in the down track direction, is forced to have one line **22** and one space **20**. Information is encoded by the presence or absence of a reversal in the intermediate interval extending the width of the track. Unfortunately, the recording at the cross track ends of those information bits is poorly controlled and leads to noisy read back signal. That corresponds to the weakened field and corresponding noise found at the edges of conventional write heads, (ibid. van Herk, Tsang). A further difficulty of patterns such as those of Fig. 2 is that channel chips usually are binary based so Gray code cells must contain 2 or 4 subintervals; three subintervals are not usable.

The present invention avoids the problems of Gray codes by using phase encoding methods to provide absolute position information. This information is decoded from signals read at any cross track location. It is not required to accumulate data as the head is moved incrementally from a special reference position such as a crash stop.

Fig. 3A illustrates important geometrical details of the phase encoding method. The pattern is composed of lines and spaces of magnetization of alternating direction. For most printing methods the width, **w**, of such lines must be larger than some practical value, and that limit is observed in the present method. The forward sloped lines, **30**, and the backward sloped lines, **32**, are arranged periodically in both **x** and **y** directions so that the down track period **λ** is constant in the logical coordinates. Generally the ends of such lines are difficult to print so the signal is sampled or read over a restricted interval such as **A** for the forward slanted

group of lines. That group will be called the **A** burst in agreement with terms commonly used in servo systems for disk drives.

A group of backward slanted lines is designated as the **B** burst in Fig. 3A. In general it is convenient, but not necessary, to make the **B** burst a reflection of the **A** burst relative to a central vertical timing line as shown here. For the given configuration, signals from the **A** burst and **B** burst will be one half cycle out of phase. It would be possible to shift one of the bursts by one-quarter cycle in the **x** direction to generate signals that are in quadrature. That is common in systems with only one phase encoded component, and it also occurs here for each burst independently. The preferred method of demodulating the read back signal uses a channel chip with DFT. The resulting sine and cosine components of the Fourier transform are quadrature components for each burst.

Some truncated lines are omitted in the lower part of Fig. 3A to make the geometry more clear, but generally the elements will fill the entire transverse range of the pattern as suggested in Fig. 3B.

The preferred embodiment uses the DFT of the channel chip to obtain the sine and cosine transforms of each burst such as **A**, **B**, **C**, and **D** of Fig. 3B. Other bursts may be added to the pattern, and many channel chips accommodate six bursts or more. Other methods can be used to measure timing delays of the various bursts, but the DFT is readily available.. Sophisticated channel chips made for tens of millions of disk drives are very cost effective and can also be used for tape systems.

Well known methods are used to compute the phase delay of the signals from each burst relative to the sample clock that is aligned, as usual, with timing features of the first part of the servo pattern. For the example illustrated in Fig. 3B the phase angles of the four bursts would be Φ_A , Φ_B , Φ_C , and Φ_D .

It can be seen from Fig. 3A or Fig. 3B that the phase of the **A** burst will be increased or shifted in the **x** direction if the read head moves in the **y** direction. From the antisymmetric

geometry it follows that the phase of the **B** burst decreases by the same magnitude or $\Phi_A = -\Phi_B$. Therefore the sensitivity can be doubled by using the difference, $\Phi_0 = \Phi_A - \Phi_B = 2\,\Phi_A$, to measure the cross track motion. For the reflected geometry, The SNR (Signal to Noise Ratio) is also increased by a factor of $\sqrt{2}$ if the noise sources are Gaussian distributed.

The period of the symmetric bursts, **A** and **B**, of Fig. 3A is twice the height **h** of a line in the y direction. However, the phase difference, $\Phi_0 = \Phi_A - \Phi_B$, has a period or pitch, $\mathbf{p_0}$, only half as big as shown in Fig. 3B.

Because of various noise sources in every recording system there may be a small error in the sample clock and that would create an error, δ, in each of the phase values. Those errors would cancel in the difference, $\Phi_0 = \Phi_A - \Phi_B$, so it also reduces effects of timing jitter. The value of the error can be found from the sum, $\Phi_S = \Phi_A + \Phi_B = 2\delta$. This measured error, δ, can be used to correct the measured phase of bursts **C**, **D**, etc. that immediately follow the fundamental **A, B** pair of bursts.

Bursts **C**, **D**, etc., can be made with various pitches or periods in the transverse or **y** direction, but with the same period, λ, in the down track or **x** direction. The simple illustrative example of Fig. 3B includes a **C** burst with transverse pitch $\mathbf{p_1 = 3\,p_0}$, where $\mathbf{p_0}$ is the pitch of the difference, $\Phi_0 = \Phi_A - \Phi_B$. The **D** burst in this example has pitch $\mathbf{p_2 = 4\,p_0}$. It is convenient to make the sample windows of the **A** and **B** bursts equal, but it is generally reasonable to decrease the widths of subsequent bursts used for absolute position determination.

Experience has shown that the phase of such bursts can be measured with errors smaller than about one per cent of a cycle of 2π radians. Variations of the phases are shown in polar form in Fig. 4 as the head is moved in the y direction over a distance about 13 times the pitch $\mathbf{p_0}$ of the fundamental **A, B** pair. Fig. 4A shows variation of the fundamental difference, $\Phi_0 = \Phi_A - \Phi_B$, and the integral cycles are marked with numbers **0, 1, 2, ... , 12, 13, ...** at angle zero. Fig. 4B plots Φ_C for the same motion, and numbered markers indicate the phase of the

C bursts at the start of each cycle of the fundamental difference. The pitch of the C burst is three times that of the fundamental difference so Φ_C advances at one third the rate of Φ_0. Similarly Fig. 4C shows Φ_D which advances at one fourth the rate of Φ_0.

Exaggerated crosshatched sectors in Fig. 4 suggest the errors or uncertainties in each of the three phase measurements at positions corresponding to zero phase of the fundamental Φ_0. It is sufficient that the error regions of the higher order phases, Φ_C and Φ_D, do not touch. Then it is always possible to uniquely determine the cycle number of the fundamental phase, Φ_0, and hence the absolute position for all fundamental cycles **0** to **11 = 3*4-1**.

As in all such measurements it is possible to determine the phase of each burst or pair of bursts only within one revolution. With no loss of generality the phases can be constrained to the interval $0 \leq \Phi < 2\pi$. A method to select the appropriate cycle of the fundamental phase is explained by Fig. 5 for the same example of Figs. 3B, 4A, 4B, and 4C. The higher order phases, Φ_C and Φ_D, are plotted versus the transverse displacement **y** normalized relative to the fundamental pitch p_0. All three phases are equal to zero at the start, but the higher order phases change at their different rates. Challenges occur when the fundamental phase Φ_0 must jump from a value near **0** to a value near 2π. Those jump points are marked by the row of integers, **j**, corresponding to the number of the cycle beginning at that value of the displacement **y**.

At those locations the phase Φ_C also jumps from one to the next of its segments of one-third of the fundamental cycle, and Φ_D jumps to its next segment of length one-fourth of the fundamental cycle.

As suggested by the crosshatched sectors of Fig. 4, small errors may occur in the measurements, but the ambiguity is resolved by first deciding the value of the fundamental phase Φ_0 with its possible, small error. If Φ_0 is found to be zero or slightly larger, then Φ_C and Φ_D are both chosen to be in the segments corresponding to values of **y** just larger than that at the ideal jump point. Cases where Φ_0 is slightly less than 2π results in segment

numbers for **C** and **D** phases corresponding to **y** values just under those at the ideal jump point.

Because the phase angles, Φ, are confined to the range $0 \leq \Phi < 2\pi$ it follows that the integers designating the subintervals are also limited and repeat modulo the number of segments. The number of phase segments for a burst is the ratio of its pitch to the fundamental pitch, p_0. It is necessary to decode the combinations of segment indices of the **C** and **D** bursts in order to find the cycle number of the fundamental **A**, **B** difference.

In Fig. 5 the markers indicate the start of each segment, and the rows of integers under the horizontal axis correspond to the segments of Φ_0, Φ_C, and Φ_D respectively. The index **k** for the **C** burst repeats modulo **3**, and index **m** for the **D** burst repeats modulo **4**. Because the integers **3** and **4** are relatively prime (have no common factors) the combinations of **k** and **m** are unique over the first **3 x 4 = 12** fundamental cycles. Therefore each of the first 12 **k-m** pairs identify a unique fundamental cycle numbered **j** where **j** is contained in **[0,1,2,...,11]**. For larger values of **j** the **k-m** pairs would repeat.

The values of **k** and **m** are computed from the phase measurements, and then the value of **j** can be computed for this example from the following algorithm.

ALGORITHM 1

$$j = M * \mathrm{mod}(k - m + M,\ K) + m$$

Here the modulo function **mod** is the remainder obtained by dividing the first integer argument by the second integer argument in parentheses. Algorithm 1 is valid for any two relatively prime numbers **K** and **M** where $M > K$ and $\mathrm{mod}(M, K) = 1$. Those conditions are satisfied by any pair of successive integers, that is, with $M = K + 1$, as well as by many other pairs.

The following decoding algorithm is valid if **mod(M, K) = 2**:

ALGORITHM 2

```
r = mod( m – 1 + K, K )
if r = 0
        t = 0
else if r is even
        t = K – r/2
else
        t = ( K – r ) / 2
end
j = t * M + m
```

Additional bursts can be included in the compound phase pattern to extend the length of the unique combinations of the sub indices provided the number of values for each index has no common factor with any other corresponding number. For example **K = 3, M = 4, N = 5** would give unique codes **k, m, n** for **j** running from **0** to **3 * 4 * 5 –1 = 59.**

It can be shown that an odd integer and the next two integers have no common factor, so such a triple can be used to form a unique code sequence of length equal to their product. Then the previously described algorithms can be combined to decode the triplets as follows.

ALGORITHM 3

```
K is odd
M = K + 1
N = M + 1
r = N * mod( m – n + M*2, M ) + n
s = mod( r – k + K, K )
if s = 0
        t = 0
else if s is even
        t = K – s / 2
else
```

```
    t = ( K − s ) / 2
end
j = t * M * N + r
```

Some examples of the successive triplets described above are:

K	M	N	K*M*N
5	6	7	210
11	12	13	1716
19	20	21	7980
51	52	53	140556

Many other combinations of relatively prime integers can be found and similar algorithms can be set up to decode the corresponding sets of segment numbers to find the index j of the fundamental cycle. Then the fraction of the fundamental cycle can be added to compute the transverse coordinate as

$$y = (j + \Phi_0 / (2 \pi)) * p_0 \qquad (1)$$

PREFERRED EMBODIMENT

The previous methods using relatively prime numbers of sub intervals could be decoded more easily when the numbers of sub intervals were about the same for all higher order bursts. However, errors in measurements of the phase angles are nearly independent of the pitch of the bursts, and that allows use of an encoding method similar to positional number systems such as our conventional decimal notation.

As a simple example consider that the first higher order burst has a pitch **R** times greater than the fundamental pitch p_0. Then **R** sub intervals can be accurately identified in each cycle. Let the pitch of the next burst be **R** * **R** times p_0. For each additional more significant burst its pitch is **R** times that of its predecessor. The 2π phase range of each burst can be accurately divided into **R** equal phase segments that each identify one cycle of the preceding, less significant burst.

If there are **Q** of such higher order bursts, and if the segment indices, k_q, are measured for each burst, with $0 \le k_q \le R - 1$, then the cross track position, **y**, can be computed as

$$y = [\, k_{Q-1} * R^{Q-1} + k_{Q-2} * R^{Q-2} + \ldots + k_1 * R + k_0 + \Phi_0 / (2\pi) \,] * p_0 \qquad (2)$$

This absolute position can be mapped in various ways to define the physical spacing of tracks in the transverse direction. For example, in hard disk systems some heads may function better than others, and regions near the inner radius of a disk may perform differently from regions near the outer radius. The final, physical mapping or track spacing can be adjusted to optimize robustness and capacity of the drive.

Fig. 6 shows a simple example of such phase variations versus transverse coordinate **y**. The radix, or ratio **R**, is **4** in this case. The servo control computations are often done with a binary computational unit or DSP (Digital Signal Processor) operated in integer format. Some calculations such as multiplication and division by **R** can be done with simpler shift and add operations if **R** is a power of **2**.

In Fig. 6 the segment indices are in the rows designated as **k**, **m**, and **n**, and the index of the fundamental cycle or the integer part of the quantity in square brackets in equation 2 is

$$j = k * 4^2 + m * 4 + n \qquad (3)$$

Of course, the number of phase segments could be changed for each burst, and then the position values would not be simple powers of a single ratio **R**, as in equation 2, but would be the product of ratios of all lower order bursts.

In any case the ambiguity caused by the usual system noise at each segment boundary is resolved by working from the phase of the fundamental burst upward through each more significant burst, as explained above. That results in a total error no larger than that of the fundamental burst.

For track oriented servo systems the on-track position must be maintained with deviations no greater than a small fraction of the nominal track pitch. Therefore narrower tracks require more servo information blocks, and that reduces the area available for user data or other purposes.

The compound phase system of the present invention offers a means, as suggested in Fig. 7, to ameliorate the space requirements for servo information. Some of the servo blocks comprise more elements such as a synchronization segment **60** for a timing PLL (Phase Locked Loop), a SAM (Servo Address Mark) **62**, certain flags **64** for index or other markers, a forward fine burst **30**, a backward fine burst **32**, and higher order position bursts **70**, **72**, and **74**. Such complete servo blocks can be combined with the user data areas **78** and with abbreviated servo blocks such as those shown comprising only the fine position bursts **30** and **32**.

Effective disk drive or tape transport control systems may use timing signals recovered from the servo blocks to regulate the motion of the medium and to synchronize the servo readback clock to the recorded pattern. At start up the information retrieved from the complete servo blocks can be used to initialize the timing systems. When the medium speed is nearly correct then the delay δ of the fundamental bursts of the abbreviated blocks can also be used for final tuning of the timing.

If this compound phase pattern is used for the final servo information of a disk drive and if the disks are printed before assembly into a drive then the pattern may be slightly eccentric relative to the axis of rotation. Well known self-test methods can be used to measure the eccentricity of the pattern, and the final data tracks can either be computed to form concentric tracks or the tracks can follow the eccentricity of the printed servo pattern. In either case predictions of the control system can be verified and corrected at each of the fundamental or fine position chevrons. Adding one or more bursts of higher significance to the reduced servo blocks can enhance the robustness or tolerance of the system to minor disturbances.

During rapid seek motion an advantage of the positional encoding system is that it is only necessary to decode the more significant bursts of the complete servo blocks. As the transverse seek speed decreases it is easier to decode the less significant bursts, and finally in settling and tracking modes the fundamental or finest bursts are decoded and used in the control system.

In addition to the above mentioned examples, various other modifications and alterations may be made without departing from the invention. Accordingly, the above disclosure is not to be considered as limiting and the appended claims are to be interpreted as encompassing the entire spirit and scope of the invention.

REFERENCE NUMERALS

10 timing and Gray code or coarse position information of prior art

14 elements of edge of burst fine position information of prior art

16 some wide lines of the prior art

18 some large spaces in Gray code of prior art

20 a completely open space in a Gray code of the prior art

22 a completely filled line in a Gray code of the prior art

30 forward slanting lines of a phase burst

32 backward slating lines of a phase burst

36 forward slanting lines of a coarse phase burst

38 forward slanting lines of another coarse phase burst

60 synchronization elements

62 servo address mark (SAM)

64 flags such as index

70 a coarse phase burst

72 another coarse phase burst

74 another coarse phase burst

78 user data

CLAIMS

What is claimed is:

1. An information pattern for determination of a transverse position from compound phase measurements of signals obtained from a sensor that scans a surface in a particular "track" direction.

2. The means set forth in claim 1 wherein the pattern comprises bursts having various rates of change of phase as the transverse position is changed.

3. The means set forth in claim 2 wherein the phases of various bursts are combined mathematically to enhance the resolution or to provide absolute position information.

4. The means set forth in claim 3 wherein phase cycles of certain higher order bursts are subdivided into segments each of which corresponds to a full phase cycle of a lower order burst.

5. The means set forth in claim 4 wherein the numbers of phase segments of all higher order bursts are relatively prime integer multiples of cycles of the least significant or finest phase pair.

6. The means set forth in claim 5 wherein the relatively prime integers are chosen such that simple algorithms are used to decode the segment numbers measured for each higher order burst to determine the unique cycle number (within the product of factors) of the fundamental phase pair.

7. The means set forth in claim 6 wherein combination of the decoded number of the fundamental cycle along with the fractional portion of the phase of the fundamental provides an absolute position coordinate with range equal to the product of the relatively prime numbers of segments in higher order bursts and with accuracy of the least significant or fundamental pair.

8. The means set forth in claim 4 wherein the phase of a certain burst or the phase difference of a pair of bursts forma a finest or fundamental phase measure and phase cycles of successively higher order are subdivided into an integer number of segments each of which corresponds to a full cycle of the previous, less significant burst.

9. The means set forth in claim 8 wherein the value of the segment index in a burst denotes the integer number of fundamental cycles equal to said index multiplied by the total number of segments in each of the bursts of lesser significance.

10. The means set forth in claim 9 wherein the position relative to a zero reference is computed as total number of fundamental cycles obtained as the sum of each segment index times its value plus the fractional cycle measured for the fundamental phase unit.

11. The means set forth in claim 10 wherein the number of segments in each burst is equal to a common integer or radix which yields a positional number system for the transverse coordinate similar to commonly used binary, octal, decimal, and hexadecimal systems.

12. The means set forth in claim 10 wherein certain information blocks of the pattern are abbreviated in order to increase the portion of the surface available for other purposes.

13. The means set forth in claim 10 wherein the bursts of higher can be decoded to provide a coarse position coordinate useful for rapid transverse motion over large strokes.

ABSTRACT OF THE DISCLOSURE

A type of servo pattern suitable for tracking systems in magnetic recording devices such as floppy disks or linear tape or thin hard disks or in other machines. The patterns comprises several phase encoded elements that provide an absolute transverse position coordinate by computations with channel chips commonly used in magnetic recording disk drives.

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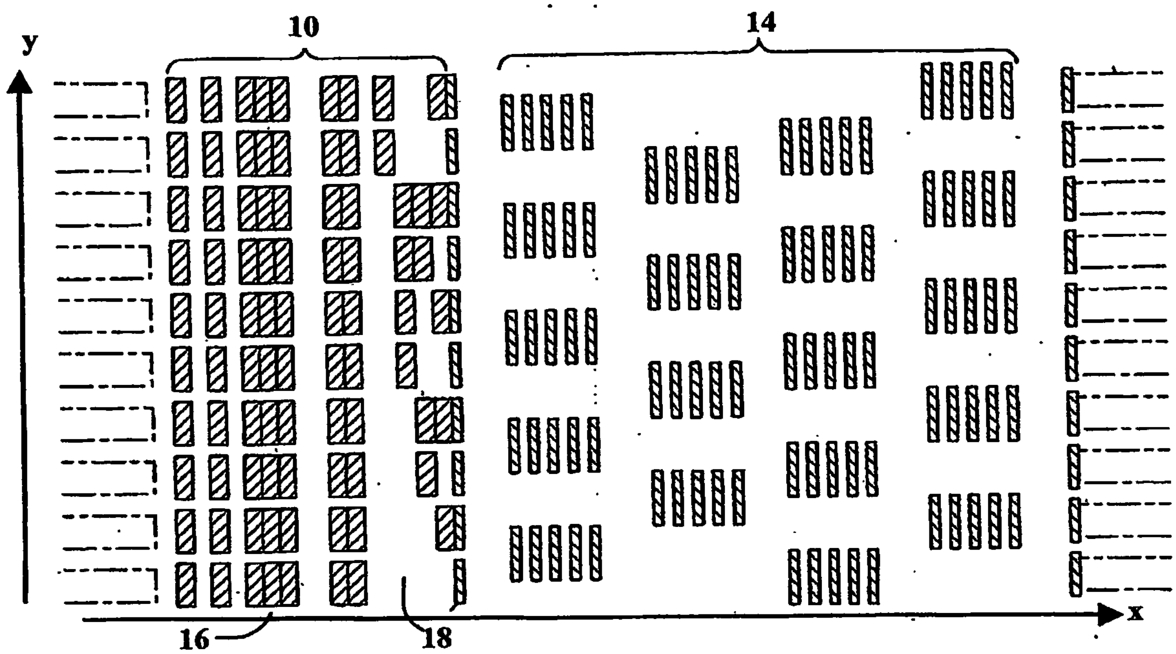


FIG. 1 PRIOR ART From US 6,469,848

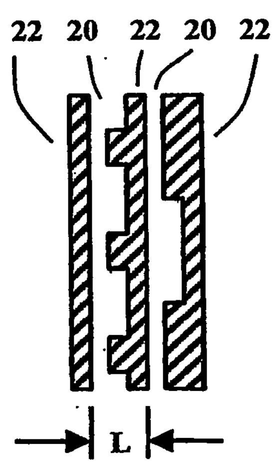


FIG. 2 PRIOR ART

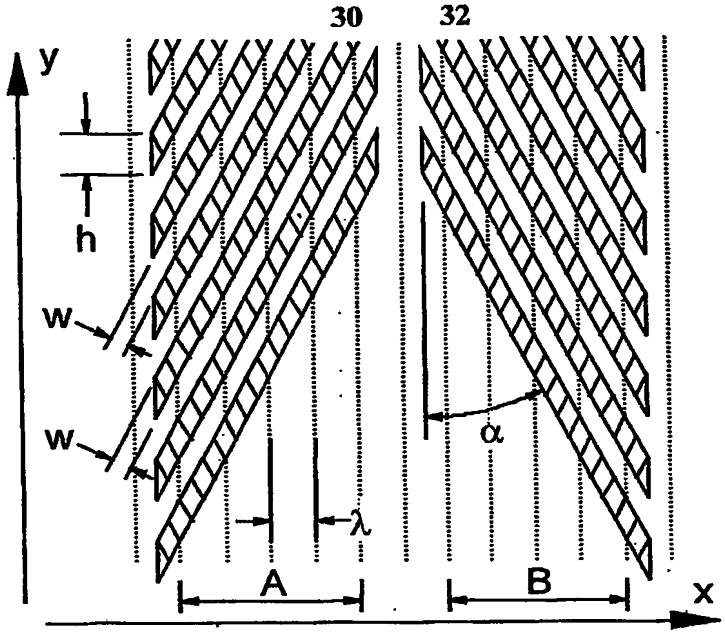


FIG. 3A

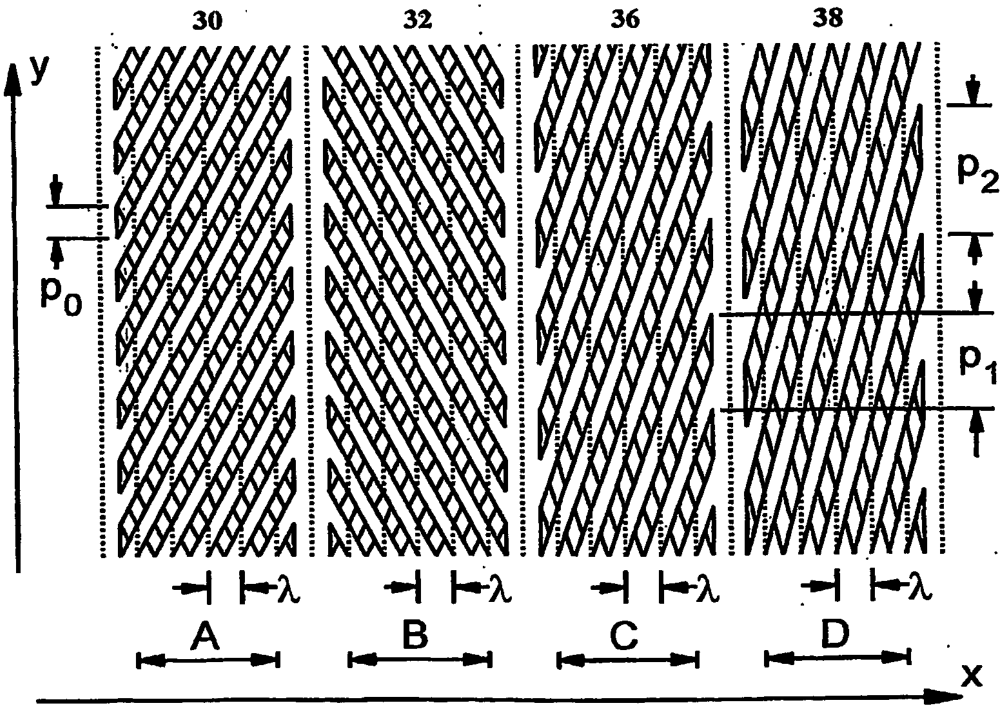


FIG. 3B

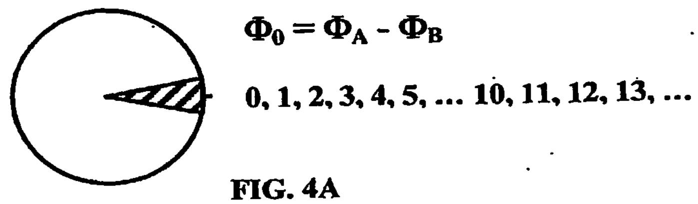


FIG. 4A

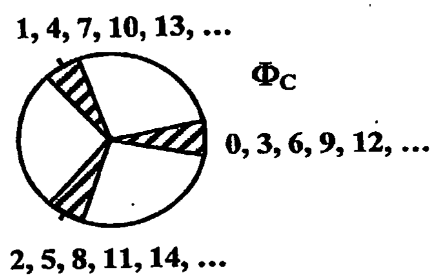


FIG. 4B

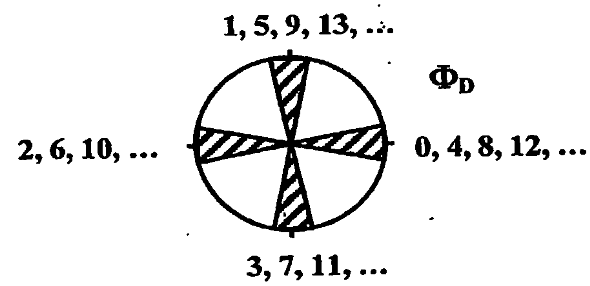


FIG. 4C

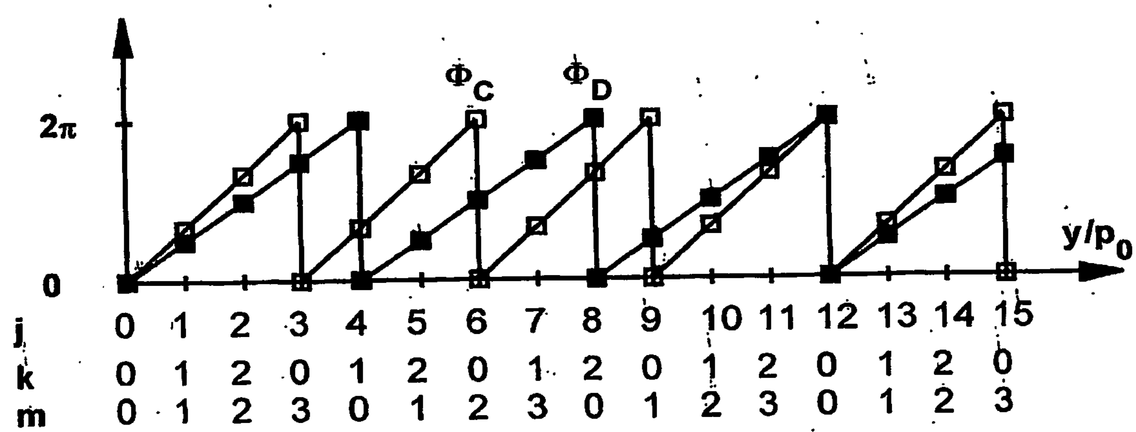
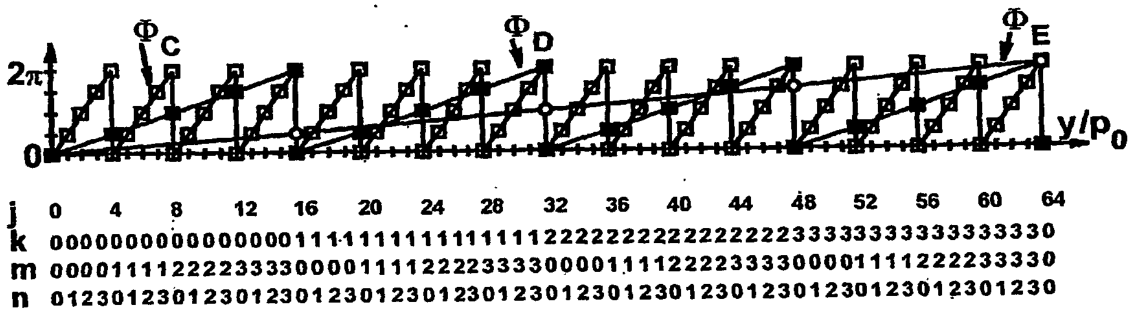


FIG. 5



Φ_C
Φ_D
Φ_E
2π
0
y/p_0
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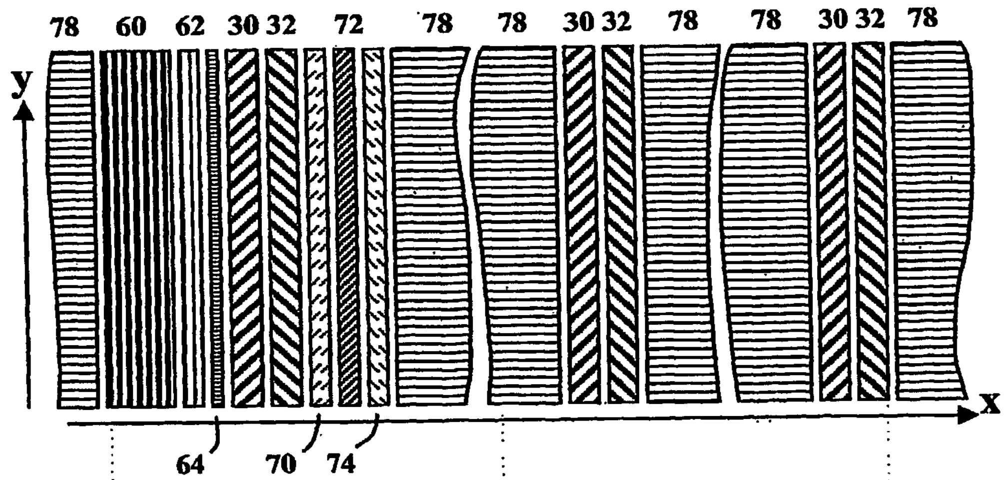
m 00001111222233330000111122223333000011112222333300001111222233330
n 01230123012301230123012301230123012301230123012301230123012301230

FIG. 6



78
60
62
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FIG. 7